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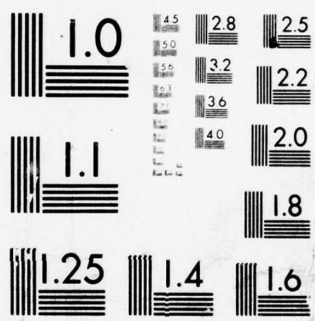


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NRL Memorandum Report 3663

# ELF Noise Observed in the Vicinity of Large Jet Aircraft


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*Communications Sciences Division*




December 1977




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| 20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)<br>Measurements were made of the electromagnetic fields generated by a KC-135 aircraft in a frequency range of 20 to 200 Hz. The measurements were made using an array of four parallel plate electric field antennas and one ferrite-core magnetic field antenna placed on and near the aircraft; the noise was measured during powering of the engines to as high as 90% of full power while the aircraft was held in place on the ground. The measured noise was complex and difficult to interpret but could be divided into two parts, one arising from various electrostatic<br>(Continues) | | |

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20. Abstract (Continued)

square root of (Hz)(dBE)

sources and the other from vibrations of the antenna on the airframe. The peak electrostatic noise component varied between -35 dB relative to 1 v/m $\sqrt{Hz}$ (dBE) and -10 dBE, depending on antenna location. These amplitudes are 40 dB to 65 dB greater than typical atmospheric noise. The largest vibration-related component was +8 dBE. The vibration related noise probably is caused by variations in capacitance between the antenna and the airframe due to vibration of the mounting rather than vibrations within the antenna. Aircraft-generated noise of these magnitudes will make reception of the transmitted ELF signal difficult at all ranges from the transmitter.

## CONTENTS

# ELF NOISE OBSERVED IN THE VICINITY OF LARGE JET AIRCRAFT

## I. Introduction

The Navy's extremely low frequency (ELF, ~ 75 Hz) strategic communications system is intended to permit reliable, secure, low data rate communications from a single transmitter located in the continential United States to submarines at operational depth and at ranges of several thousand kilometers. The ability for the Air Force Airborne Command Post (ACP) aircraft to monitor the messages broadcast on the ELF system is highly desirable, and hence a practical aircraft-mounted ELF receiving antenna is required. This report discusses the results of an effort to develop a suitable airborne ELF antenna. The specific goals of the project are twofold:

- Develop an ELF antenna suitable for aircraft mounting that has sufficient sensitivity to detect transmissions from the Navy's ELF transmitter;

- Use this antenna (and possibly other sensors) to characterize the electromagnetic noise generated by an ACP aircraft.

This report briefly summarizes the development of the electric field parrallel plate antenna (PPA), which was selected as the best configuration for an airborne ELF antenna, and discusses in detail the results of a series of ground measurements of aircraft-generated ELF noise.

We conclude from our ground measurements on a testbed KC-135 aircraft that the aircraft-generated noise levels in a bandwidth of 20-200 Hz can exceed the mean atmospheric noise levels by as much as 40 dB. This noise is partially from electrostatic charges present in jet exhaust and partially from vibrations of the antenna on the airframe. The PPA was carefully designed to minimize the effect of vibrations, but vibration-induced noise was evident. Aircraft-generated noise of this magnitude will make reception of the transmitted ELF signal difficult at all ranges from the transmitter.

Note: Manuscript submitted November 10, 1977.

## II. Antenna Development

Possible candidates for an airborne ELF antenna include the following types:

- Electric Field

  Vertical whip
  Parallel plate capacitor

- Magnetic Field

  Air-core loop
  Ferrite-core loop
  Superconducting Quantum Interference Device (SQUID).

Magnetic field air-core loop antennas at frequencies of 30-130 Hz must be impractically large to provide sufficient sensitivity. Ferrite-core loops can be made sufficiently compact but are susceptible to intermodulation distortion. A SQUID antenna developed for submarine use [1], can provide sufficient sensitivity, but the need for cryogenic cooling is unattractive for the airborne application. All magnetic field antennas at these frequencies are subject to motion noise arising from movement of the sensor in the earth's magnetic field.

An electric field antenna would seem to be the antenna type of choice for the airborne ELF application. A standard whip antenna, however, is electrically very small and hence has an extremely large capacitive reactance, making it difficult to match an amplifier to the antenna. The PPA, on the other hand, has a much smaller capacitive reactance, thus easing the matching problem. Sufficient electrical height can be obtained with a plate separation of 1.3 cm.

Table I lists the characteristics of the PPA developed for the measurements described in this report. The PPA consists of a flat planar sheet of melamine dielectric. Melamine was selected on the basis of vibration tests that demonstrated its lower vibration-induced noise in comparison to the other tested dielectrics (polystyrene, polyethylene, nylon, and bakelite). Conducting silver paint was applied to the opposite sides of the dielectric to constitute the plates of the antenna. Vibration of a cable that would ordinarily be used to connect the two plates of the antenna to the input of the preamplifier would introduce noise in the system because of the high impedance. To minimize this noise, the preamplifier was placed in a 4-cm hole cut in the center of the dielectric, short rigid leads were used to connect the antenna plates to the preamplifier, and the entire hole was filled with an epoxy resin. This technique kept the length of the leads to a minimum and prevented the leads from moving with respect to the plates.

TABLE I. Parallel Plate Antenna Parameters

| | |
|---|---|
| Dimensions | 30.48 x 30.48 x 1.27 centimeters |
| Relative Dielectric Constant | 7.5 |
| Capacitance | 486 pF |
| Impedance (75 Hz) | 4.37 MΩ |
| Effective Height | 0.17 centimeters |

## III. Aircraft Measurements

### A. Overview

An airborne ELF receiving antenna will be subjected to the following sources of noise:

(1) Atmospheric noise from close and distant thunderstorms;

(2) Noise associated with vibration of the aircraft that induces noise in the antenna;

(3) Noise associated with electrostatic emissions from charged particles in the jet engine exhaust;

(4) Noise associated with the impact of charged particles upon the aircraft (precipitation static);

(5) Noise from corona discharge;

(6) Noise due to the discharge of insulated structures to the metallic body (streamering).

The first source of noise is the basic determining noise level for an ELF communications system, and an airborne antenna will be subject to essentially the same atmospheric noise spectral density as an antenna on the ground. Noise sources (2) to (6) will introduce additional noise, and the feasibility of aircraft reception of ELF signals depends on the degree to which these sources exceed the atmospheric noise level. The assessment of noise sources (2) to (6) logically consists first of static ground measurements of aircraft noise followed by airborne measurements, although static ground measurements only permit noise sources (2) and (3) to be investigated. This report discusses only ground-based measurements on a KC-135 aircraft and addresses attempts during these ground based measurements to separate the contributions of source (2) and the remaining sources,

which are all basically electrostatic in character. In static ground measurements, the main contributor to electrostatic-related ELF noise will be source (3). Noise sources (4) - (6) are potential sources only during flight of the aircraft. These tests were conducted during run-up of the engines to power as high as 90% of full power while the aircraft was held in position. The tests were conducted on 10 and 11 September 1976 at Wright-Patterson Air Force Base, Dayton, Ohio.

B. Description of Noise Tests

Four E-field sensing antennas and one H-field sensing antenna were installed on and near the aircraft. The E-field antennas were the PPA with integral preamplifier described above. The H-field antenna was a conventional ferrite-core loop antenna with a self-noise level of -170 dB below 1 $A/m/\sqrt{Hz}$ (hereafter abbreviated dBH) at 75 Hz.

Figure 1 contains a picture and an outline drawing of the aircraft, showing the location of the antennas. The forward antenna was attached securely to the aircraft's frame but was electrically insulated from the aircraft's skin. The aft antenna was also insulated from the aircraft's skin but was not directly fastened to the aircraft's frame; rather, the aft antenna was attached to a 1.0 cm thick honeycomb plate, which was in turn fastened to a fiberglass pod secured to the aircraft's frame. The center antenna was located approximately 30 cm below the aircraft's skin and was securely attached to a rigid stand. The H-field antenna was placed on the ground and was weighted down with lead bars to minimize vibration. The axis of the H-field antenna coil was oriented vertically. The vertical orientation was used because of the lower background atmospheric noise level; however, this orientation causes the coil to be relatively insensitive to skin currents flowing on the aircraft fuselage.

In addition to these antennas, another PPA was placed on the ground approximately 10 meters off the left wing (this antenna is designated the off wing antenna). The center and off wing E-field antennas and the H-field antenna were to serve as reference antennas, with the off wing antenna providing the amplitude of the background atmospheric E-field noise. The center and H-field antennas, because they are not attached to the airframe, should help identify noise generated by the aircraft jet engine. These reference antennas should allow the mechanical vibrational noise measured by the two antennas attached to the aircraft to be separated from jet exhaust noise.

A block diagram of the measurement apparatus is shown in Figure 2. The output of the antenna-preamplifier was fed to a band-pass filter to limit the measurement to frequencies from about 20 to

200 Hz, and the 60 Hz notch filter was used to remove power frequency noise. The output of the notch filter was amplified by the post amplifier and then recorded on analog magnetic tape. The H-field antenna did not incorporate an integral preamplifier but used very similar signal conditioning. The time code generator signal recorded on the analog tape provides a convenient means of identifying the various portions of the tape recordings. The AC power for the apparatus was derived from the 400 Hz generator of a ground power unit when the engines were off or from the engine-generated aircraft power when the engines were in operation.

The test procedure consisted of the following sequence:

(1) ground power unit on and all aircraft engines off;

(2) aircraft engines running at 65% of full power (FP) and ground power off;

(3) aircraft engines running at 75% FP, ground power off;

(4) aircraft engines running at 85% FP, ground power off;

(5) aircraft engines running at 90% FP, ground power off.

In addition, the engines were powered in a slow constant acceleration-deceleration sequence from 65% to 90% FP and back to 65% FP. Normal aircraft cruising speed is in the range of 85% to 90% FP.

C. Data Reduction and Analysis

The analog tape-recorded noise measurements were analyzed using a Federal Scientific model UA-6B analog spectrum analyzer with averager. The spectra are presented in Figures 3 through 12 for the five sensors used to obtain the noise measurements and are averaged for 3.33 minutes to remove transient effects. The resolution of each spectrum is 1.0 Hz, and the spectral amplitude is scaled in equivalent field strength incident upon the antenna in a 1 Hz bandwidth.

The features of the PPA spectra can be divided conveniently into two parts: a more or less smooth increase in amplitude as the frequency decreases below 50 Hz, and a series of peaks that appear in the spectrum above 60 Hz. The appearance of the 1/f amplitude dependence at the lowest frequencies is accenuated by the rolloff of the system bandwidth at 20 Hz, producing a "peak" at the filter cut-off, and by the notch filter at 60 Hz. Figure 3, for example, for the 90% curve appears to show a peak from 20 to 60 Hz that would be absent if the filters were not present. To varying degrees this increase at low frequencies is seen in all PPA spectra. In some cases, such as Figures 3, 6, and 11, the frequency at which the rise

begins is as high as 150 Hz. The amplitudes of the spectra at about 20 Hz are considerably larger on 11 September than on 10 September; note also that this behavior is apparent in the off-wing PPA, as well as the PPAs on and near the aircraft.

The 1/f amplitude dependence is not present, however, in the H-field spectra. This absence suggests that the "1/f noise" arises from electrostatic sources associated with charged particles on the aircraft skin or from charged particles being emitted in the engine exhaust. The increase in amplitude and frequency extent seen in Figures 3, 4, 8, and 9 as the engine power is increased indicates that a portion of the electrostatic noise probably arises from the jet engine exhaust. On the other hand, Figures 5, 6, and 10 show relatively little dependence of the spectral amplitude below 100 Hz on engine power setting.

The various peaks in the spectra above about 50 Hz apparently result from vibrational motion of the antennas on the airframe, for those antennas mounted on the aircraft (Figures 3, 4, 8, and 9). The spectra for the PPA's not mounted on the airframe (Figures 5, 6, 10, and 11) are relatively free of peaks above 50 Hz, other than powerline fundamentals and harmonics. The exception is a large peak at about 150 Hz in the off-wing and center antennas whose amplitude increases with engine power setting. A peak near 150 Hz is not obvious in the aircraft-mounted antennas, possibly because it is masked by more intense vibration-related noise.

The H-field antenna shows spectral tones whose amplitude and frequency vary in a smooth manner with engine power. Figure 13 is a time-amplitude-frequency plot of the H-field antenna output during a constant acceleration-deceleration run. The frequency variation of several tones with power level is clearly visible. In addition, an increase in spectral amplitude occurs near 200 Hz that can also be seen in Figures 7 and 12. The tones are probably the result of a rotating part (electric motor, fuel pump, etc.) whose rotational rate is a function of engine power. No such frequency-dependent tones were apparent in any of the PPA spectra. Figures 14 through 18 are graphs of the minimum noise field intensity for the five antennas. Indicated on each figure is the mean level of the fields measured when the system was powered by the ground power unit. Comparisons of Figures 14 through 18 reveals the following:

- The aft antenna shows the strongest dependence of noise level on engine speed, followed by the forward antenna.
- The antennas not attached to the aircraft show relatively little variation of the minimum noise level with engine speed.
- The interference generated by the ground power unit is

large; in some cases, the noise exceeds the aircraft-emitted noise. Recall that the ground-power unit was not used during the tests when the engines were powered. The excessive interference by the ground power unit does not allow us to establish a reliable value of the background atmospheric noise level for the tests.

In an effort to assess the contribution to the noise from the aircraft's jet engines, data were recorded at the 90% engine speed using only two of the aircraft's four engines. These data are presented in Figure 19 for the off wing, forward and aft antennas with either the two inboard or two outboard engines in operation. The off wing antenna spectra display relatively little difference between the two operation conditions, but the difference is consistent with the hypothesis that the 1/f dependence at low frequencies and the peak near 150 Hz are the result of noise from the emission of charged particles in the jet engine exhaust. That is, the peaks are lower when the engines further from the PPA are powered. The forward and aft antennas, on the other hand, do not show a consistent pattern. However, evidence deduced above suggests that these antennas are dominated by vibration noise, rather than electrostatic noise. Hence, in Figure 19 the curves probably differ because the vibrational frequencies and resonant modes in the aircraft frame depend on which pair of engines is powered.

## IV. Conclusions

1. The ELF electric field noise measured by an array of parallel plate antennas (PPA) placed on and near a KC-135 aircraft during static run-up of the engines displayed two identifiable features: (1) low frequency noise apparently of electrostatic origin; and (2) spectral peaks probably related to aircraft vibration.

2. The low frequency noise increased in amplitude as the frequency decreased. At 20 Hz and 90% full power, the amplitude varied between -35 dBE and -10 dBE, depending on antenna location on the aircraft. These amplitudes are 40 dB to 65 dB greater than typical atmospheric electric field noise.

3. The vibration noise consisted of spectral peaks occurring between 60 and 150 Hz. Their largest amplitudes (in equivalent electric field noise referred to the input) at 90% full power were -11 dBE for the forward-mounted antenna and +8 dBE for the aft-mounted antenna.

4. An additional strong peak was observed near 150 Hz in the antennas not mounted on the aircraft; this peak is apparently masked in the aircraft-mounted antennas by vibration-related noise. Since this peak was not observed in the magnetic field antenna, it is assumed to be of electrostatic origin. The peak had an amplitude at 90% full power of approximately -30 dBE.

5. The PPA used in these measurements was carefully designed and shown during vibration table measurements to be very insensitive to vibration noise. The large vibration-related peaks are probably due to a modulation of the capacitance between the aircraft and the antenna, due to motion of the antenna mounting, rather than relative motion of the two plates of the antenna. This hypothesis is supported by the fact that the vibration noise was largest in the aft antenna, which was mounted less firmly to the airframe than the forward antenna. This source of noise could be greatly reduced by making the antenna an integral part of the aircraft skin.

6. The measurements reported here suffered from several defects that should be corrected in future measurements of aircraft noise. The aircraft was parked at Wright-Patterson Air Force Base at a site within 400 m of a large radar and powerline. Consequently, the data are contaminated to an unknown degree by electromagnetic interference (EMI) and 60 Hz powerline interference. Future tests should be conducted at an installation where the aircraft can be located at least 2000 m. from the nearest EMI sources. Battery operation of the system was not possible because of the unavailability of a battery-operable tape recorder; hence, background noise measurements with all aircraft power off required a ground power unit that itself generated excessive noise. Because of this circumstance, we were unable to obtain reliable measurements of background atmospheric noise levels.

7. These measurements demonstrated also that the ELF electric fields measured near large, multi-engined aircraft such as the KC-135 are complex and difficult to interpret. Similar problems have been encountered by other investigators who have measured ELF electric fields, even when such measurements are made in locations intentionally chosen to be electrically quiet. For example, Ginsberg [2] has reported that ELF electric field noise measurements made at remote sites on Guam and Malta are heavily contaminated by local electrostatic noise arising from such sources as high winds and rain.

ACKNOWLEDGEMENT

We are indebted to C. Spencer, the Test Director of WPAFB, for his assistance during the tests. We also gratefully acknowledge the assistance provided by C. Colston and N. Boykin of WPAFB and W. Meyers of NRL.

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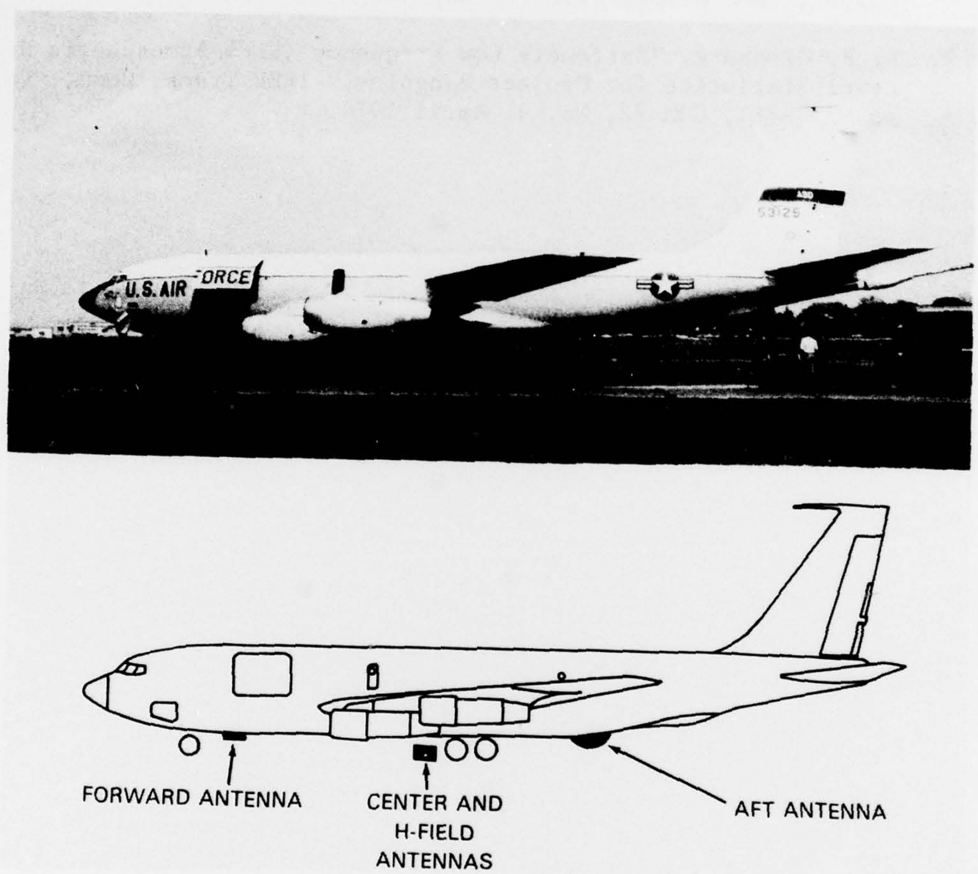
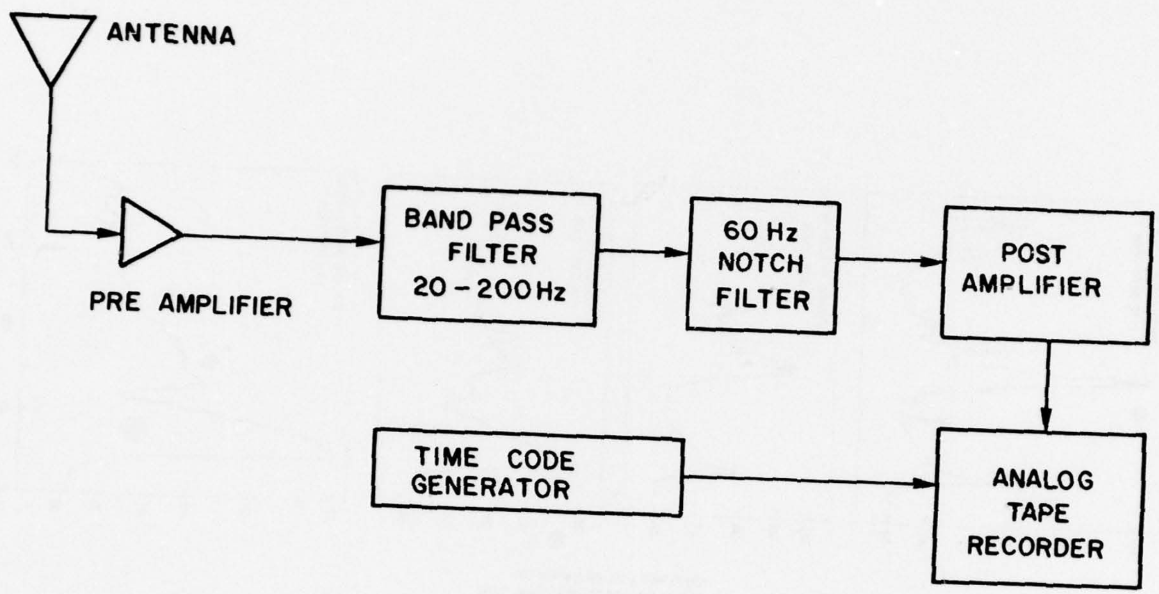



**Fig. 1 — Location of antennas on the KC-135 aircraft**




RECORDING SYSTEM

Fig. 2 - ELF noise recording apparatus

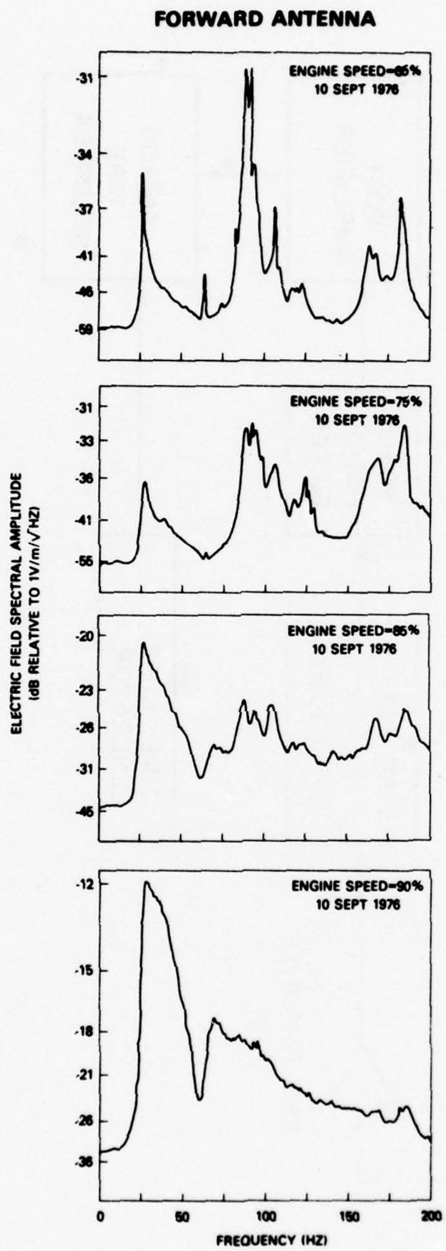



Fig. 3 - Variation of electric field spectral amplitude with frequency and engine power setting. 10 September 1976. Forward antenna.

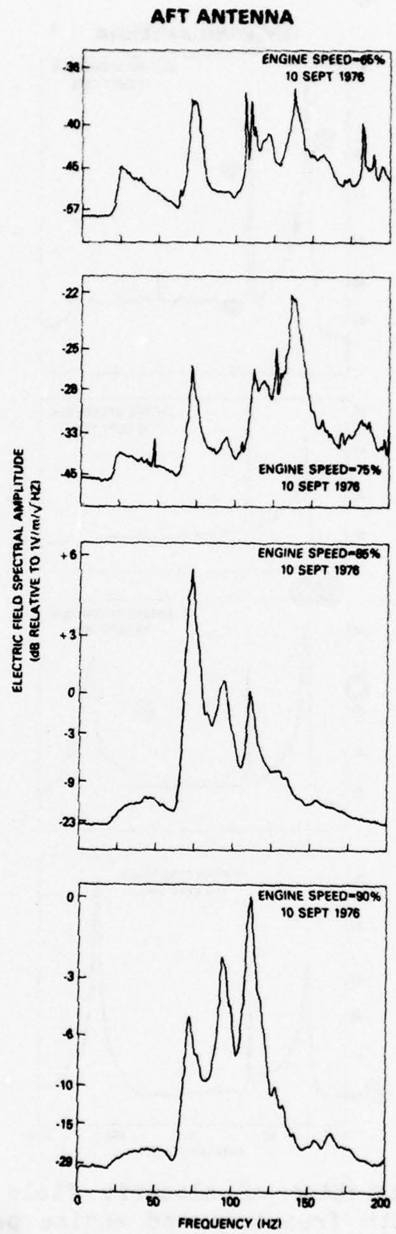



Fig. 4 - Variation of electric field spectral amplitude with frequency and engine power setting. 10 September 1976. Aft antenna.

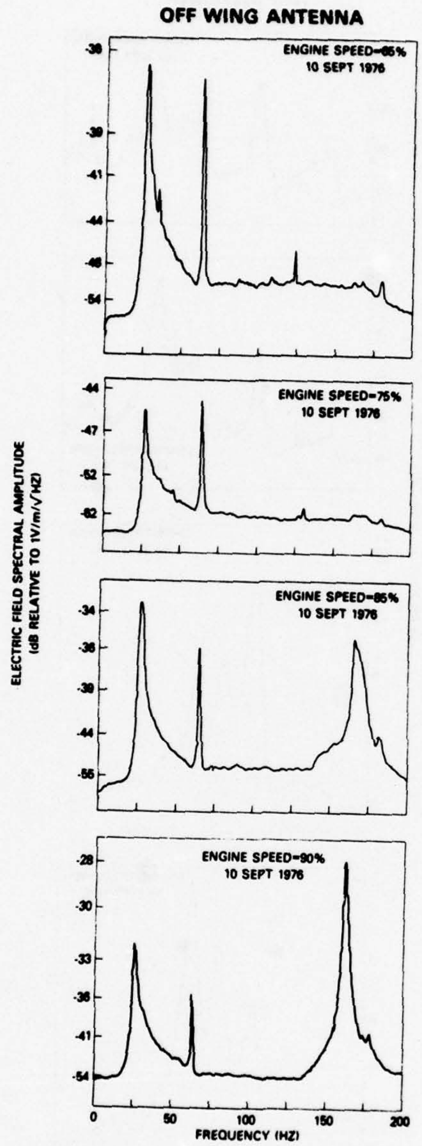



Fig. 5 - Variation of electric field spectral amplitude with frequency and engine power setting. 10 September 1976. Off wing antenna.

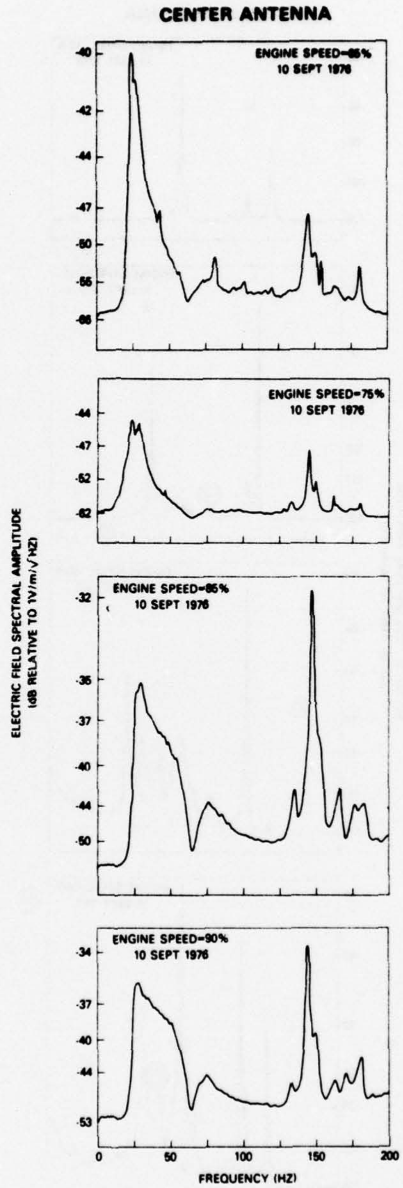



Fig. 6 - Variation of electric field spectral amplitude with frequency and engine power setting. 10 September 1976. Center antenna.

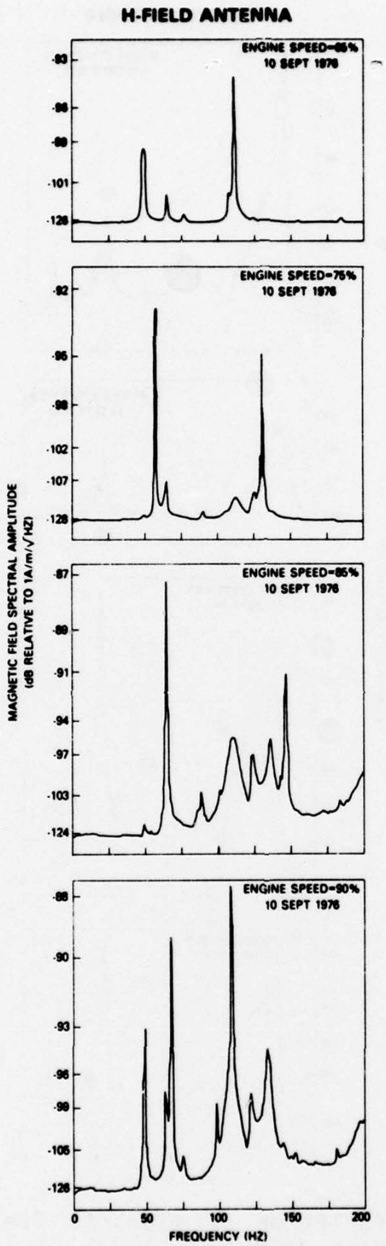



Fig. 7 - Variation of magnetic field spectral amplitude with frequency and engine speed. 10 September 1976. H-field antenna (mounted near center).

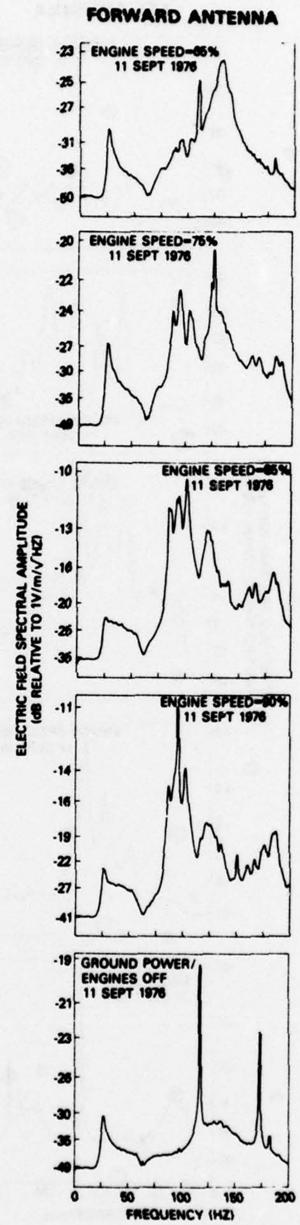



Fig. 8 - Variation of electric field spectral amplitude with frequency and engine power setting. 11 September 1976. Foward antenna.

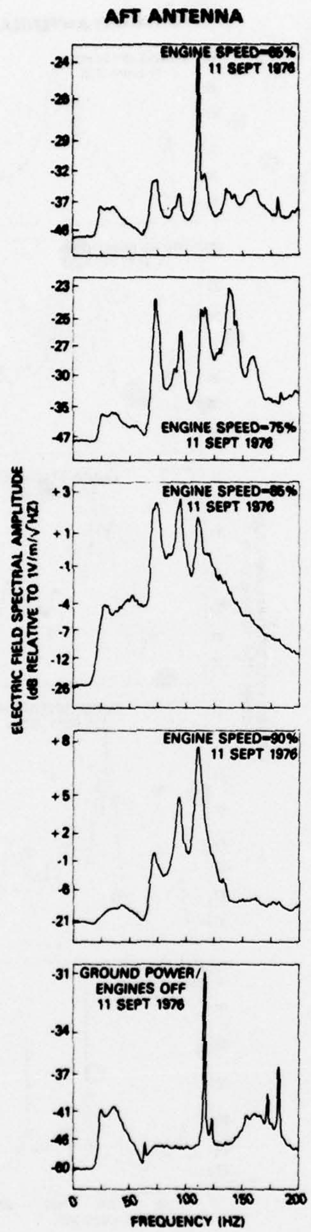



Fig. 9 - Variation of electric field spectral amplitude with frequency and engine power setting. 11 September 1976. Aft antenna.

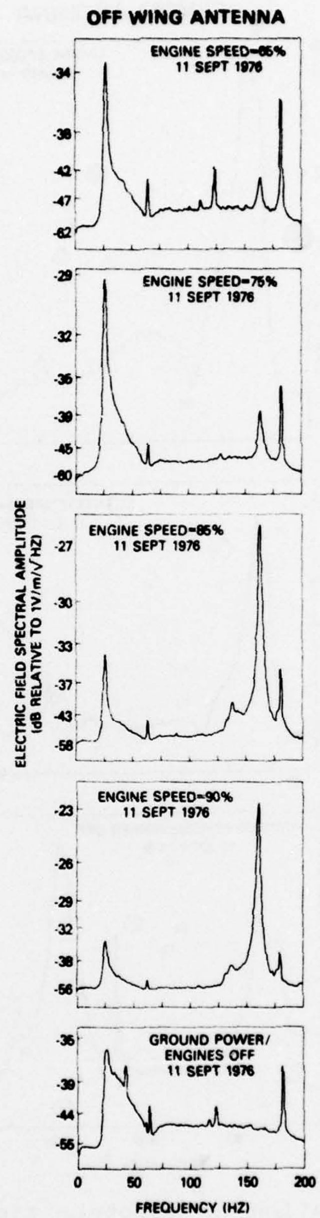



Fig. 10- Variation of electric field spectral amplitude with frequency and engine power setting. 11 September 1976. Off wing antenna.

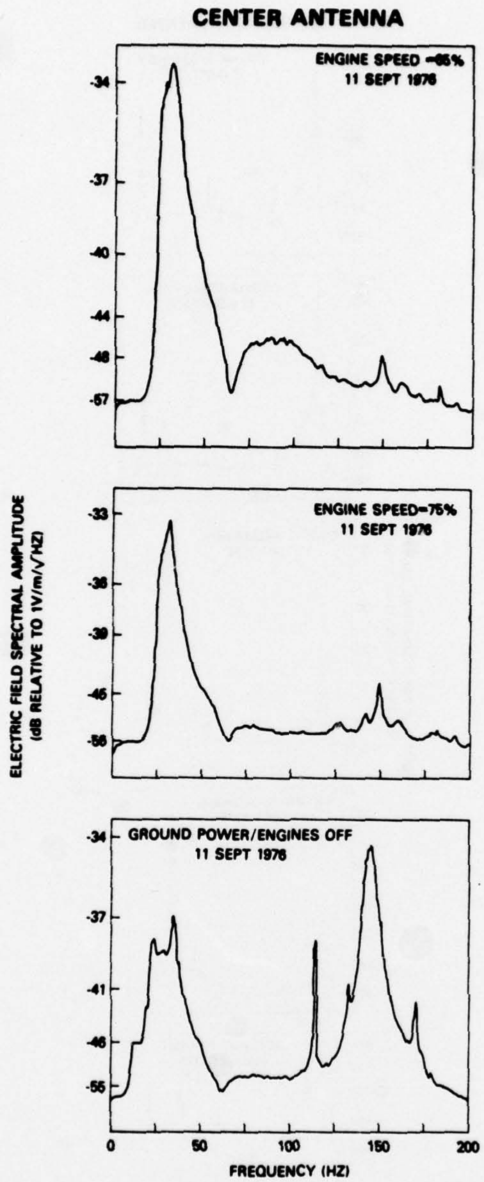



Fig. 11- Variation of electric field spectral amplitude with frequency and engine power setting. 11 September 1976. Center antenna.

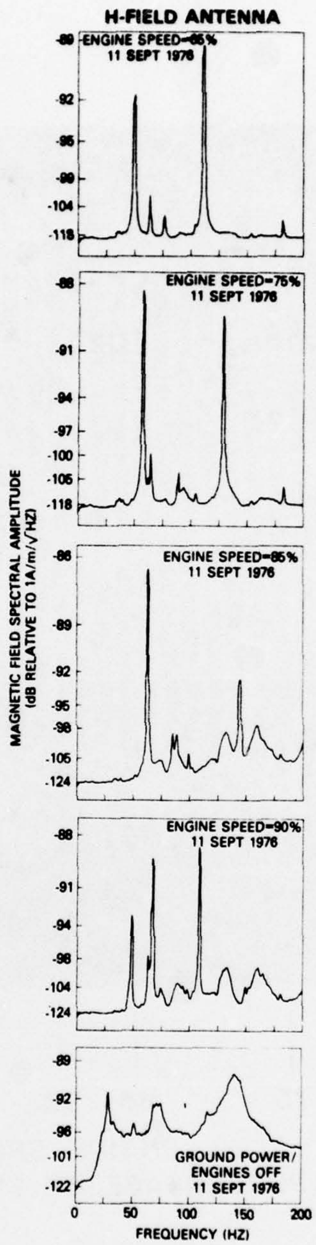



Fig. 12- Variation of magnetic field spectral amplitude with frequency and engine power setting. 11 September 1976. H-field antenna (mounted near center).

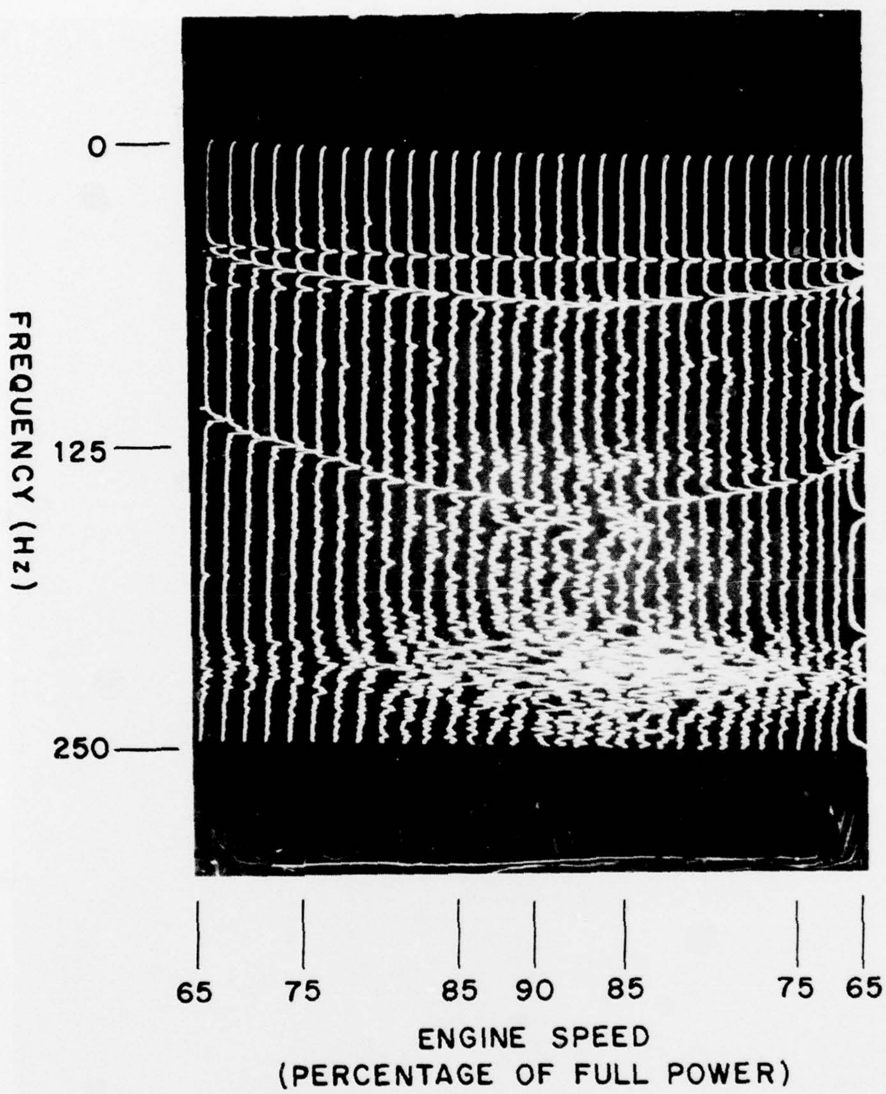



Fig. 13- Spectra of the H-field antenna output as a function of engine power setting. Spectral resolution is 0.5 Hz.

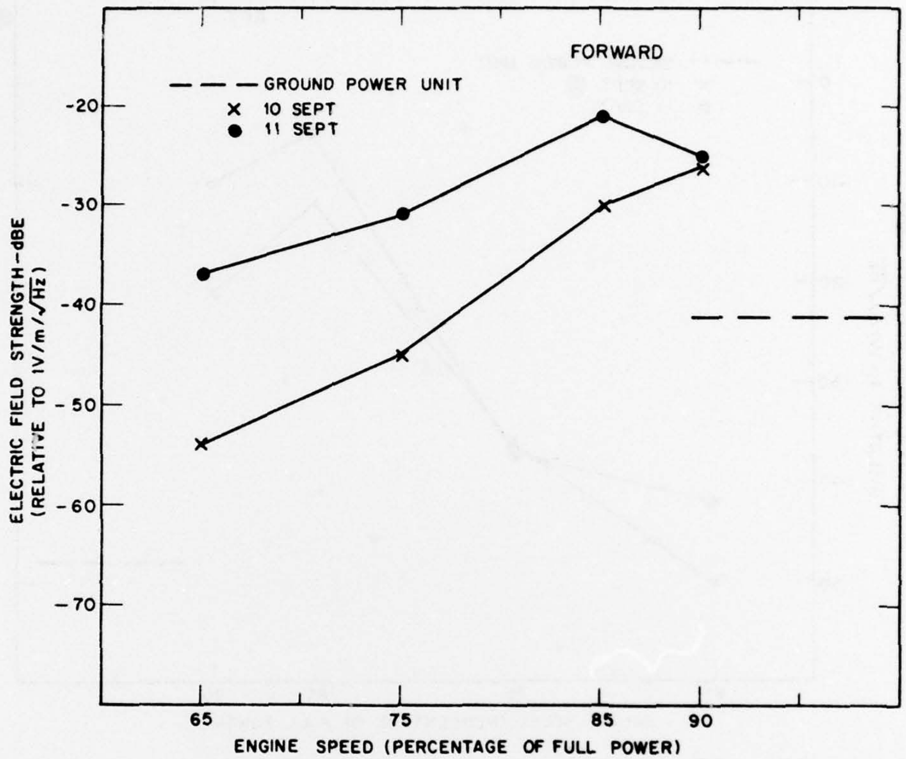



Fig. 14- Minimum measured electric field strength as a function of engine power setting. Forward antenna.

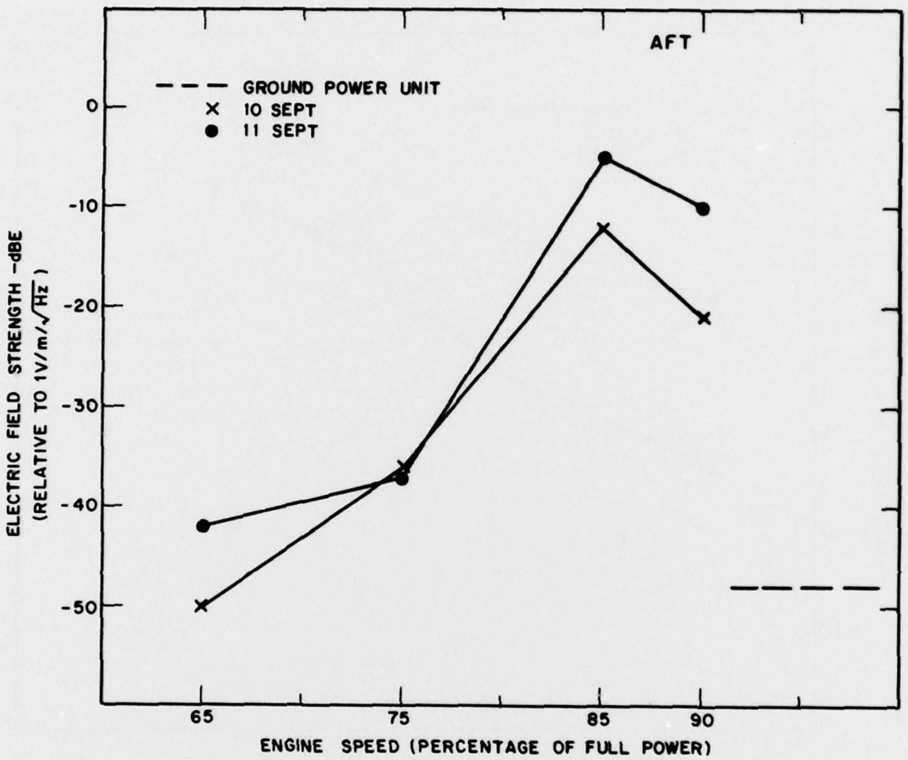



Fig. 15- Minimum measured electric field strength as a function of engine power setting. Aft antenna.

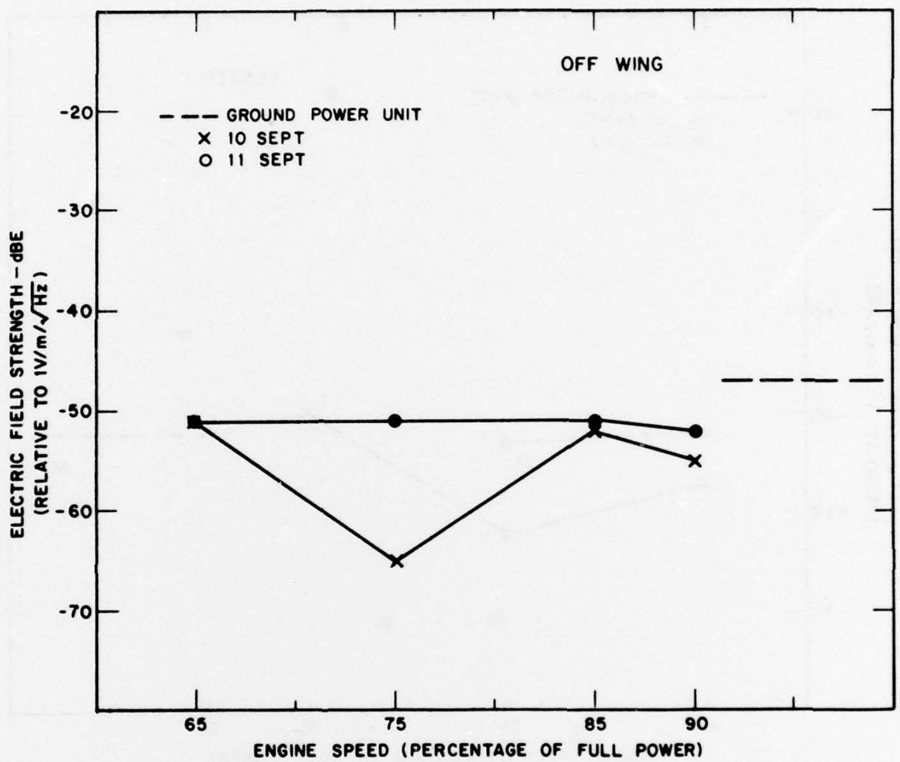



Fig. 16- Minimum measured electric field strength as a function of engine power setting. Off wing antenna.

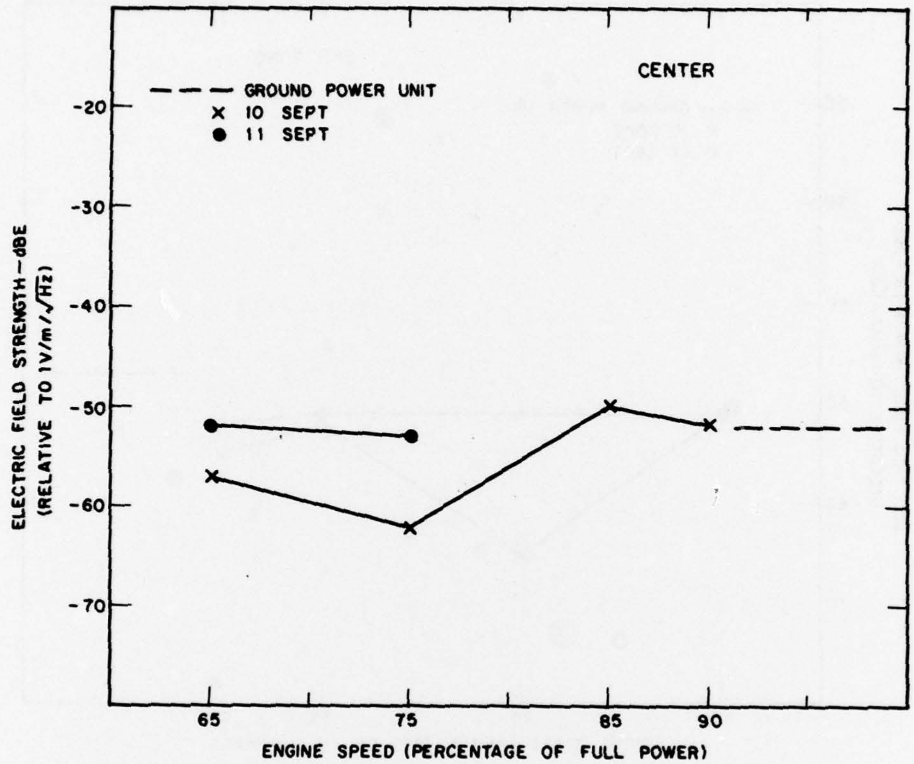



Fig. 17- Minimum measured electric field strength as a function of engine power setting. Center antenna.

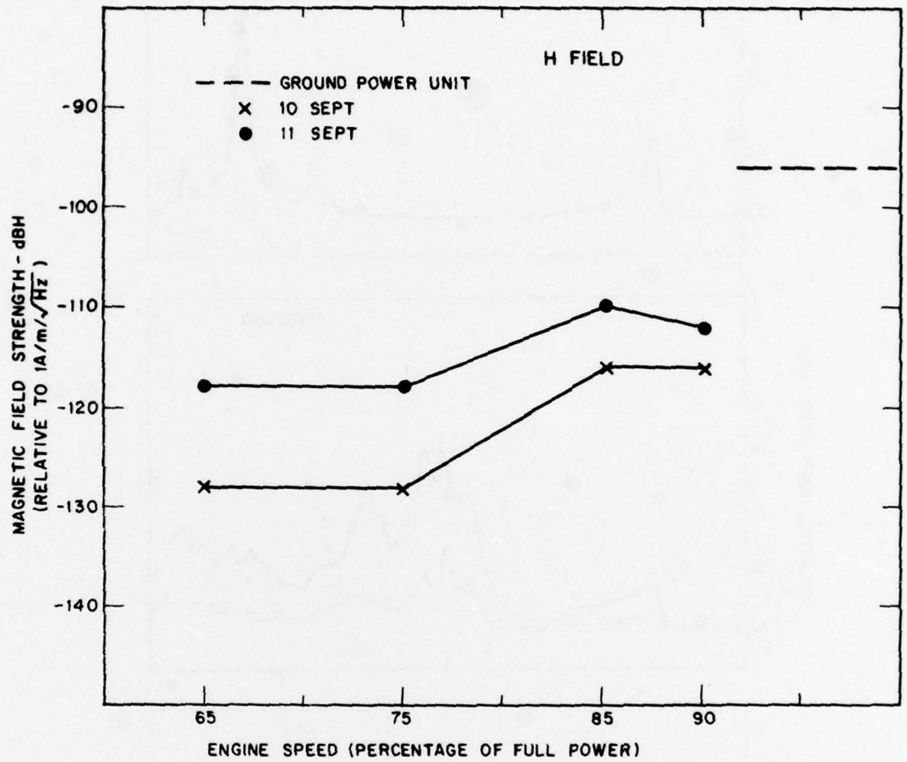



Fig. 18- Minimum measured electric field strength as a function of engine power setting. H-field antenna.

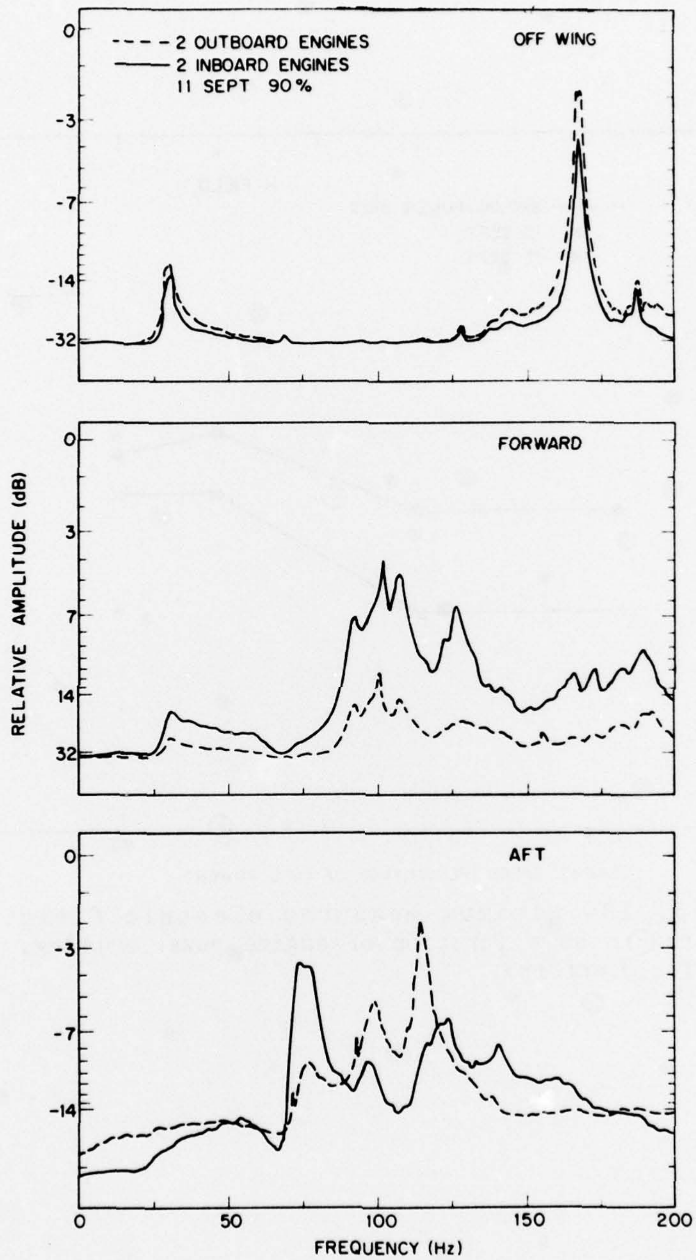



Fig. 19- Dependence of antenna spectra on the particular pair of engines that are powered.

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